TECHNICAL NOTES:

A TRACTOR-MOUNTED MULTIPLE-PROBE SOIL CONE PENETROMETER

R. L. Raper, B. H. Washington, J. D. Jarrell

ABSTRACT. *Determining soil compaction profiles requires fast sampling systems due to changing moisture conditions with time. Soil cone penetrometers are commonly used for this purpose, but acquiring the many readings required due to spatial and data variability can take long periods of time. A multiple-probe soil cone penetrometer was constructed and tested for the purpose of measuring cone index values throughout the entire soil profile from trafficked middle across a crop row to untrafficked middle. This machine has been successfully used in numerous studies and offers the capability of obtaining soil strength information throughout an entire field in relatively short periods of time.*
Keywords. *Soil compaction, Penetrometer, Multiple-probe soil cone penetrometer, Soil strength, Cone index.*

Soil cone penetrometers are quite useful for quickly determining soil strength and various levels of soil compaction. Basic manual versions with dial indicators for penetration force are quite simple but can be difficult to read unless one person stops the unit at pre-determined depths and a second person records depth and force values. For many years researchers have attempted to simplify the usage of the soil cone penetrometer by complicating the design. Some have designed hand-operated recording penetrometers that do not require a second person and can be inserted continuously into the soil (Carter, 1967; Hendrick, 1969; Prather et al., 1970). Tractor-mounted penetrometers were also developed to eliminate the manual labor requirements associated with obtaining these measurements (Williford et al., 1972; Smith and Dumas, 1978; Wilkerson et al., 1982).

Determining statistical significance in measurements obtained from a soil cone penetrometer is sometimes difficult owing to the large variability in the data. One effective method of combating this difficulty is to acquire a large amount of data for analysis. Time constraints and changing soil conditions require that soil cone pentrometer data be obtained quickly. However, for large experiments it is difficult to acquire the necessary data within any sort of reasonable time. During one experiment that involved two traffic systems, four tillage systems, four replications, five locations within the plot, and five positions across the row, more than three days were required to obtain the 800 sets of force-depth data with a tractor-mounted single-probe soil cone penetrometer (Raper et al., 1994). The need for a soil cone penetrometer with multiple probes that could take several readings at once across a row was easily justified.

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OBJECTIVE

Develop a multiple-probe soil cone penetrometer (MPSCP) that could be tractor-mounted and used to determine soil strength profiles across the row quickly and easily.

DEVELOPMENT OF DESIGN CRITERIA

CONE SHAFT AND TIP

ASAE Standard S313.2 (ASAE, 1998) governs the design of the soil cone penetrometer probe tip and shaft. Two design sizes are available for use; a 20.27-mm (0.798-in.) diameter base cone with a 15.88-mm (0.625-in.) diameter shaft for soft soils and a 12.83-mm (0.505-in.) diameter base cone with a 9.53-mm (0.375-in.) diameter shaft for hard soils. The larger size was chosen for this hydraulically powered soil cone penetrometer due to the stronger driving shaft as recommended by the standard.

PROBE

A frontal-view diagram of the MPSCP shows the location of the multiple probes (fig. 1). These probes were designed

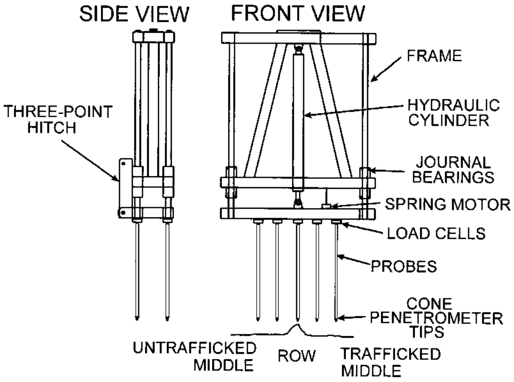

Figure 1–Front and side views of the MPSCP.

to be movable allowing for row spacings of up to 1.2 m. Five probes were mounted across the row with one in the row middle on the left side, a second midway between the row and the row middle, a third directly in the row, a fourth midway between the row and the other row middle, and the fifth in the other row middle on the right side. When extremely hard soil conditions were experienced, the second and fourth probes were removed to allow for increased force on the remaining three probes. In situations where row position was not important as in forests or pastures, the data from all probes were averaged to achieve even greater precision in determination of cone index.

Maximum depth of penetration was governed both by the length of the probes and the stroke length of the cylinder. Typical depths of probe length have been 0.91 m (36 in.) or 0.76 m (30 in.) with the frame having a limitation of slightly more than 1 m (39 in.).

FRAME

The frame was composed mainly of $10 \times 10 \times 0.6$ cm ($4 \times 4 \times 1/4$ in.) members and was designed to handle the force requirements for all five probes. When the cylinder was attached to the tractor's hydraulic system, it was first calibrated to achieve the penetration rate of 30 mm/s (72 in./min) recommended in ASAE Standard S313.2. This rate was achieved by using flow control valves which regulate the flow of hydraulic fluid in the lines and by adjusting the operating speed of the tractor's engine.

The MPSCP was attached and lifted with the three-point hitch hydraulic system and rigidly attached to the tractor by way of two additional links. These additional links prevented the MPSCP from moving laterally or vertically while the MPSCP was being inserted into the soil. This procedure eliminated depth errors that occurred in hard soils if the weight of the MPSCP was not sufficient to force the probes into the soil. By rigidly attaching the MPSCP to the rear of the tractor, the additional weight of the tractor assisted in obtaining cone index values in firm soil conditions.

POSITIONING

When backed or pulled into the plots, the operator occasionally needs to slightly move the MPSCP to one side or the other to line up exactly over the row. This was achieved by operation of a Buffalo Scout II row-positioning unit that adjusted the penetrometer from side to side. This machine slid the probes 0.25 m (10 in.) in each direction, thus keeping the plane of the MPSCP perpendicular to the rows.

INSTRUMENTATION

The Lebow load cells, which the probes were mounted directly in, have an individual maximum capacity of 2224 N (500 lb). Each of these load cells measured cone index values of almost 7 MPa (1000 psi) before exceeding their capacity, which was usually sufficient even in most hardpan soil conditions. Typical values of cone index that stop root growth are near 2 MPa (300 psi) (Taylor and Gardner, 1963).

The depth measurement system was composed of a single Celesco constant tension spring motor that was attached to two rigid members of the frame. When the penetrometer was inserted into the soil, the movement of the frame caused the spring motor to contract, thus giving a measurement of depth.

A Somat instrumentation system was used to collect the data from the six sensors mounted on the MPSCP. The data was then periodically telemetered back to the NSDL Instrumentation Vehicle which was located at the edge of the field. This vehicle contained a computer which stored the data for further graphing and analysis.

The data was collected according to chosen time increments at an approximate rate of 5 to 10 Hz. At this frequency, data was obtained at approximate depth increments of 3 to 6 mm (0.1-0.2 in.). In cases where even more data was desired, the sampling frequency was increased.

PROCEDURE FOR OBTAINING CONE INDEX MEASUREMENTS

Obtaining cone index values began with locating the center probe over the row. The probes were then lowered until the center probe was adjacent to the soil surface. The system was then biased to zero the load cells and depth measurement system and the probes pushed into the soil. When a load on any probe was sensed, contact with the soil surface was assumed to have been made and data was recorded from that point onward. In extremely soft soil conditions, the sampler was lowered until the first cone was flush with the soil surface and data were collected from that point downward. After the maximum depth was achieved, the sampler was extracted from the soil and moved to the next sampling location.

ADDITIONAL ALTERNATIVE USES

Obtaining undisturbed cores for bulk density or soil water determination was also possible by removing the probes from the MPSCP. A tube containing an inner cylinder that had been split into 5-cm (2-in.) rings was mounted on the center bar and inserted into the soil (fig. 2). Once removed from the unit, it was opened and split into multiple increments of soil for bulk density determination. Various tips can be used on the sampling tubes in different soil conditions to minimize soil compaction due to the sampling process (Raper and Erbach, 1987).

FIELD USE

Data collected with the MPSCP consisted of six variables with five columns containing force measurements

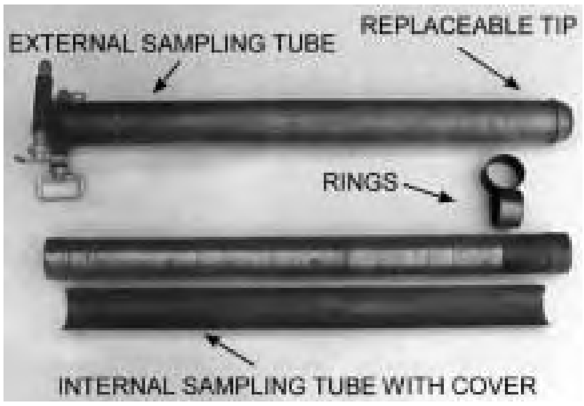

Figure 2–Undisturbed core sampling tube used for obtaining incremental values of bulk density.

from each of the attached load cells. The sixth column contained depth measurements. The force data was usually averaged within SAS (1990) to obtain average values of force for each probe at 10-mm (0.4-in.) depth increments.

The MPSCP has been used in many field studies to determine cone index or bulk density (fig. 3). One such study involved investigating the clay pan soils of central Missouri and determining the differences between native prairie sod and tillage crop land (fig. 4; Alberts et al., 1996). Because of a lack of rainfall, the soil strength was extremely high, so only three probes were used. In the prairie, the data from all three probes were averaged together due to the absence of traffic and tillage systems. Another unique study involved investigating tillage and weed elimination effects on pecan trees (Foshee et al., 1997). Trenches created several years earlier with a special tillage and cellulose burial machine were also located with the MPSCP (Raper et al., 1998a).

Determining the effect of tillage and traffic systems on soil compaction has been the most common use of the MPSCP. Developing a tillage system for the Tennessee Valley Region in North Alabama has required that soil strength be determined to evaluate the effects of shallow or deep tillage and cover crops (figs. 5; Raper et al., 1998b).

Coupling the ability of the MPSCP to determine soil strength across a row with a global-positioning system allows the variability in fragipan and hardpan profiles throughout entire fields to be determined (fig. 6; Raper and Dabney, 1998). This information is extremely useful as researchers investigate the variation in these root-impeding layers and attempt to correct it with site-specific tillage.

Figure 3–Engineer operating MPSCP which is attached to row positioner and three-point hitch.

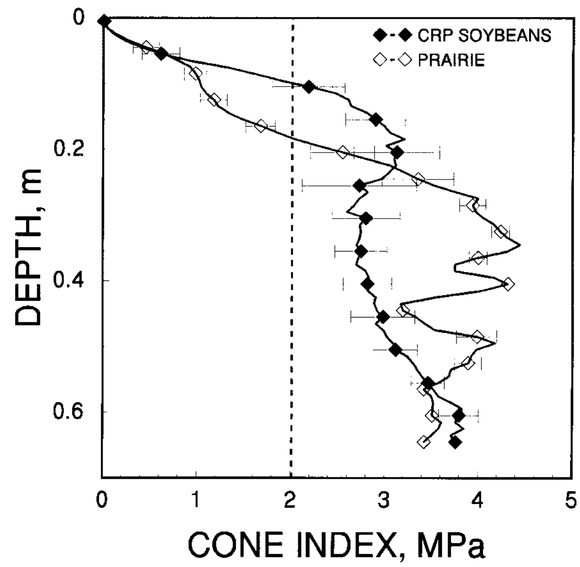

Figure 4–Cone index profiles averaged across all three probes on the MPSCP in native prairie and tilled farmland. Error bars show the error mean squares of the data.

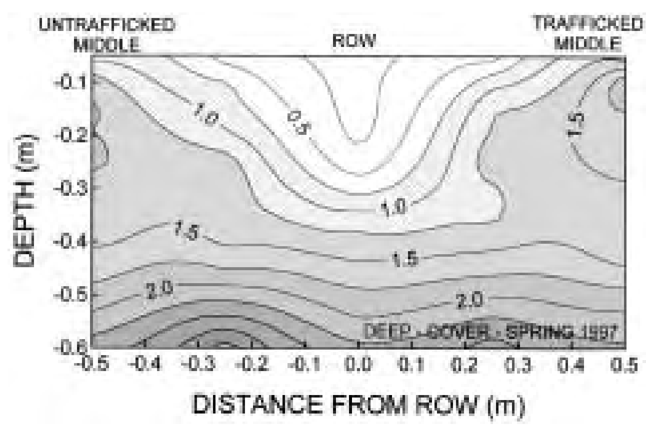

Figure 5–Cone index (MPa) profiles across the row from trafficked middle to untrafficked middle in spring of 1997 immediately after tillage showing effects of deep tillage with a cover crop.

CONCLUSIONS

A method of obtaining multiple readings of cone index across a row with one insertion has been successfully developed and used for numerous studies involving determination of the effects of soil compaction. This flexible machine can also be used to obtain core samples for bulk density determination at multiple depths. It has been a valuable addition and has increased the research capability of the NSDL.

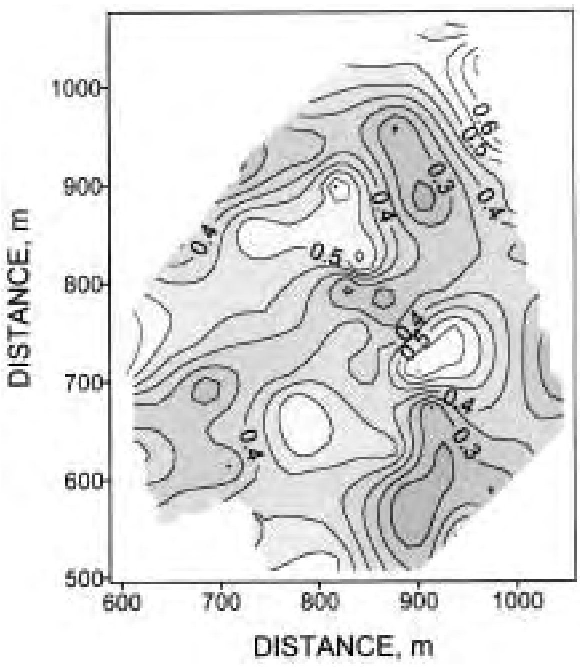

Figure 6–Depth to hardpan layer (m) contours across a field in Northern Mississippi. The hardpan depth was defined at the depth of the occurrence of the 2 MPa level of cone index.

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